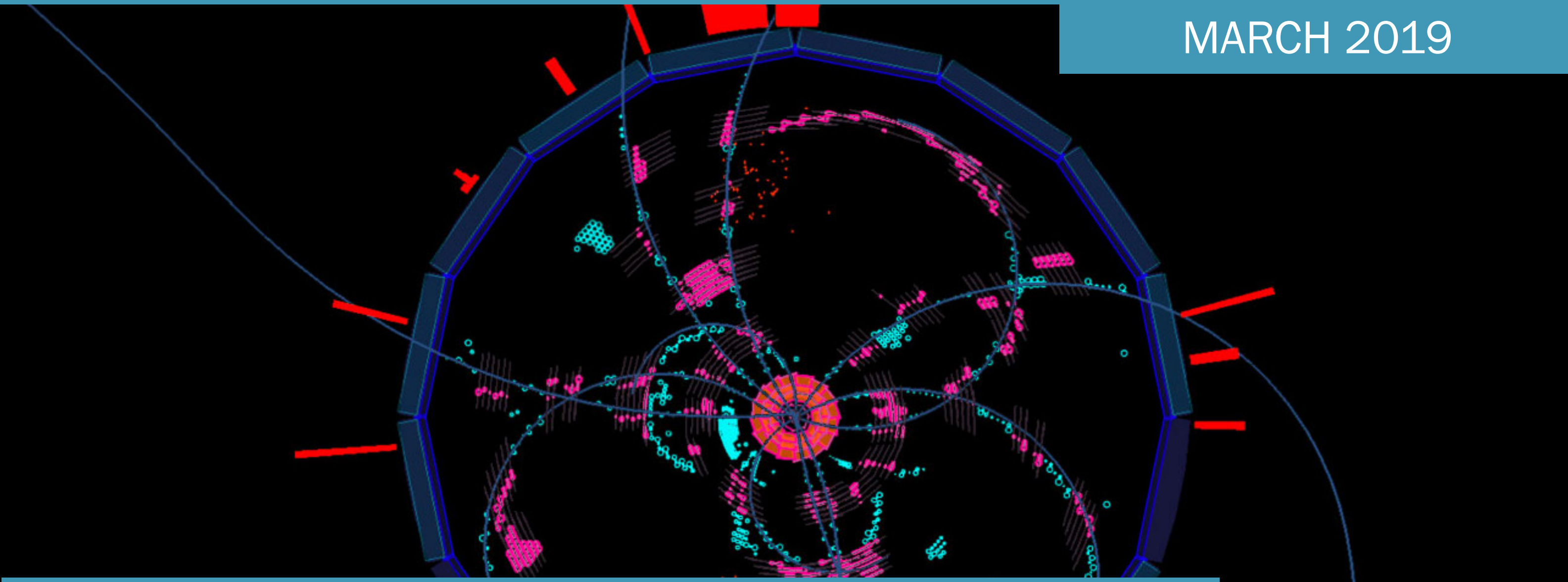

MARCH 2019

NEWSLETTER 57

Istituto Nazionale di Fisica Nucleare

INTERVIEW

NEWS

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INNOVATIVE TECHNOLOGY IN SEARCH OF DARK MATTER

Interview with Elisabetta Baracchini, assistant professor at the GSSI Gran Sasso Science Institute and INFN researcher, winner of an ERC Consolidator Grant

The ERC Consolidator Grant is addressed to excellent researchers of any nationality and age, with at least seven and up to twelve years of post-PhD experience, and a promising scientific curriculum. The 2018 award was won by Elisabetta Baracchini, assistant professor at the GSSI Gran Sasso Science Institute and INFN researcher; a grant of 1,995,719 euros. Candidates must do their work in a public or private research organisation based in one of the EU Member States or associated countries. The grant (on average of 2 million euros per grant) is for a maximum of five years and mainly covers the employment of researchers and other personnel to consolidate the work team of the beneficiaries.
The project proposed by Elisabetta Baracchini, INITIUM (an Innovative Negative Ion TIme projection chamber for Underground dark Matter searches), aims to implement an innovative detector for the direct search for dark matter, currently one of the leading sectors of investigation of fundamental physics. INITIUM envisages the development and implementation of a 1 m^3 gas Time Projection Chamber (TPC), able to reconstruct the traces of detected events in high precision 3D, thanks to a sophisticated signal-reading technology. The 5-year project envisages the installation of INITIUM at the INFN Gran Sasso National Laboratories.
We asked Elisabetta Baracchini to explain to us the investment strategy of the grant that was awarded to her, as well as the aims and development prospects of the project.

First of all, how did you come to work on a sector of fundamental research characterised by so few certainties and many unknowns: the search for dark matter?
I am motivated by the fact that we cannot explain the behaviour of most of the mass of our universe. And although there is incontrovertible proof of the existence of dark matter – that is the name we use for this unknown mass – on the true nature of this large part of the cosmos we have only hypotheses, because all the existing proof is indirect. Directly observing dark matter in our detectors would give

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us the opportunity to open a completely new window on our understanding of the cosmos and the fundamental interactions that govern it.
This is a purely experimental challenge, since direct observation of dark matter is based on the ability to detect very small amounts of energy released by an atom struck by dark matter in our detector, and on the possibility of distinguishing these events from interactions caused by common particles, which are hundreds or thousands of billions of times more frequent. This research therefore represents one of the forefronts in the development of new technologies and, in general, of new approaches to particle detection: a characteristic that makes this sector a work environment rich in stimuli and new possibilities.

Can you explain your project and its premises? In your opinion, why was it considered promising by the ERC?
My project is based on the idea of measuring and identifying the direction of arrival of the particles detected, in order to distinguish the events caused by dark matter from those due to the interactions of ordinary matter: this could be the key to the positive and unambiguous identification of a dark matter signal. This approach represents a total innovation with respect to the experiments that are currently operational and which can only detect the energy deposited.
The technique is based on a reasonable expectation. Due to the movement of the Earth with respect to the centre of our galaxy, in fact, dark matter is expected to have a preferential direction in space, unlike anything that can mimic its interaction. To do this, our project involves the use of a gas, as a detection material, and of CMOS cameras (Complementary Metal Oxyde Semiconductor, the same sensors that we have in mobile phones) capable of "photographing" the trace released by the passage of the particles in the gas, after an appropriate signal amplification.
I believe that the ERC was awarded to me because the technique we proposed is innovative for the type of research to which it applies; moreover, in the context of the development of the sector of directional search for dark matter, this innovative approach comes at the right time, since only in recent years it has reached an adequate maturity to compete with the other techniques in use.

How are you investing the grant? Has it allowed you to strengthen your team?
Approximately half of the grant will be dedicated to personnel and the expansion of the research team. In particular, the grant has already allowed me to open two 4-year positions for the next PhD cycle at the Gran Sasso Science Institute (GSSI), whose announcement was recently published. We are also counting on hiring two more post-PhD researchers in our team.

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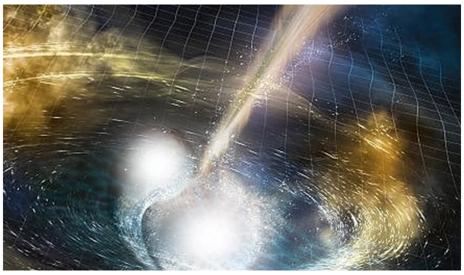
I am particularly pleased to be able to open these positions, because they will allow me to create a young and motivated team and start developing with them this and other lines of research at the GSSI. Part of the grant, amounting to approximately 600 thousand euros, will be used to purchase new components and build the detector itself, implement its services and, finally, install it in one of the tunnels of the INFN Gran Sasso National Laboratories.

What are the main difficulties you think you will have to face, in terms of technological limitations but also obstacles in the research as well as personal and team motivation process?
From a practical point of view, obviously my main concern is not being able to build a detector with competitive performance and, consequently, not being able to demonstrate the validity of our approach. In fact, the first 18 months of the project still include a phase of development of our technique, in terms of optimisation of the gas mixture, amplification type and camera sensor.
From a personal point of view, the possibility of pursuing this project is certainly a qualitative leap in my career, but also in the extent of my responsibilities and of what, in general, I will have to manage from now on. All this represents a challenge for me and a great possibility of personal and professional growth, but at the same time it sometimes scares me a little. Fortunately, our work team consists of close-knit and motivated colleagues, whose help is extremely valuable for managing and achieving the success of the project. This is why I have great confidence in the future.

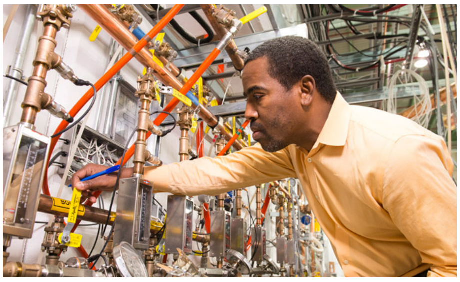
What results do you expect in the short and long term?
First of all, this ERC Grant will give us the possibility to significantly accelerate the development of our research, both from the point of view of financial availability for procurement as well as manpower. And, above all, in less than 4 years, it will allow us to complete and install at the Gran Sasso National Laboratories the first directional dark matter detector (for WIMP masses below 10 GeV/c), with performance that we hope will be competitive with the other approaches. In general, this will produce an advancement in the development of high-precision gaseous Time Projection Chambers for different applications; if it were to demonstrate the expected performance, it could actually open the way to the implementation of a dark matter directional detector on the scale of the tonne, projecting the search for dark matter into a new era. From a personal point of view, I hope that the new young research group that will be created around this experiment will become the basis for the application of our approach in other fields and for the development of other projects. ■



RESEARCH

OPEN SCIENCE: LIGO AND VIRGO PUBLISH THE DATA OF THE SECOND OBSERVATION RUN

The LIGO/VIRGO collaboration has published the data of the detectors relating to the second observation run called O2 in jargon, which started on 30 November 2016 and ended on 25 August 2017. The data was published in Gravitational Wave Open Science Centre and includes over 150 days of data recorded by both Advanced LIGO observatories and 20 days of data recorded by VIRGO which joined the two LIGOs on 1 August 2017: this is the largest set of data from latest-generation interferometers for gravitational wave detection. In this period of time, seven fusions of binary black hole systems were observed and, for the first time, the fusion of two neutron stars was observed. In addition to the data, detailed documentation is also available and links are provided to open source software tools; all the material can be freely used both for scientific studies and for educational activities.
Advanced VIRGO and Advanced LIGO are about to enter the last test data acquisition period, O3, that will start on the 1st of April. ■

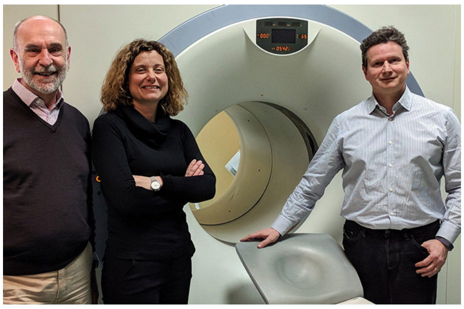


INTERNATIONAL COLLABORATIONS

FERMILAB: GROUND BREAKING CEREMONY FOR PIP-II

On 15 March, at Fermilab in the United States, the ground breaking ceremony was held for one of the most important projects for the future of physics, in which Italy provides a fundamental technological and scientific contribution. We are talking about the PIP-II (Proton Improvement Plan II) project for the construction of a new, 215 metre long superconducting linear accelerator: one of the most advanced machines for fundamental physics research that will provide the most powerful high-energy neutrino beam in the world for the DUNE (Deep Underground Neutrino Experiment) project. The ceremony was attended by representatives of American and international institutions. PIP-II uses a superconducting acceleration technology to which INFN is making a fundamental contribution through the Accelerator and Applied Superconductivity Laboratory (LASA) in Milan that will construct the niobium resonant cavities. These high-tech components, made with the contribution of Italian industry, are also used by the European XFEL in Germany and by the European Spallation Source (ESS) in Sweden, and will be installed at CERN in the evolution of LHC, which will be called HiLumi LHC.

The goal of PIP-II is to double the energy achieved by its predecessor and produce a proton beam of over 1 megawatt, approximately 60% higher than existing accelerator complexes. Once operational, PIP-II will become the heart of the Fermilab accelerator complex and will provide the proton beam for a vast research programme in particle physics that will develop over several decades. ■



APPLICATIONS

FROM GRAVITATIONAL WAVES TO CLINICAL ANALYSIS

A new study, which for data analysis exploited the tools usually used by fundamental physics, for example in the search for gravitational waves, has succeeded in confirming PET as an effective diagnostic tool for dementia with Lewy bodies (DLB). Evidence of the utility of PET in highlighting the brain regions affected by DLB comes from research published in the American journal Annals of Neurology, conducted on the largest case series ever examined: 171 patients who underwent FDG-PET (PET with radioactive glucose). The study, which made use of the European DLB Consortium international research network, was conducted by researchers from the Policlinico San Martino and from the University of Genoa, who curated the collection and clinical interpretation of the data, and by INFN researchers who developed the methodology, using optimised tools borrowed from physics research, and then performed the analysis. ■

INFRASTRUCTURES

PHASE 3 OF THE WORLD'S MOST POWERFUL B-FACTORY GETS UNDERWAY

On 22 March 2019, at the KEK Laboratory in Tsukuba, Japan, the Belle II experiment observed its first electron-positron collisions: Phase 3 of the project, in which INFN is also participating, thus got underway, following completion of the Belle II detector and an upgrade of the SuperKEKB accelerator, which is expected to reach a brightness 40 times greater than its predecessor KEKB. Belle II, on the other hand, has the ambitious goal of accumulating 50 times more data than its predecessor Belle, in order to find signals of new physics that could be hidden in the decays of B mesons, particles that contain a beauty (b) quark. The Belle II experiment, which is the result of the work of an international collaboration consisting of approximately 800 physicists from 23 different countries, is now ready, together with SuperKEKB, to become the most powerful "Super B-factory" in the world, able to produce in abundance and study B meson decays with great accuracy. ■

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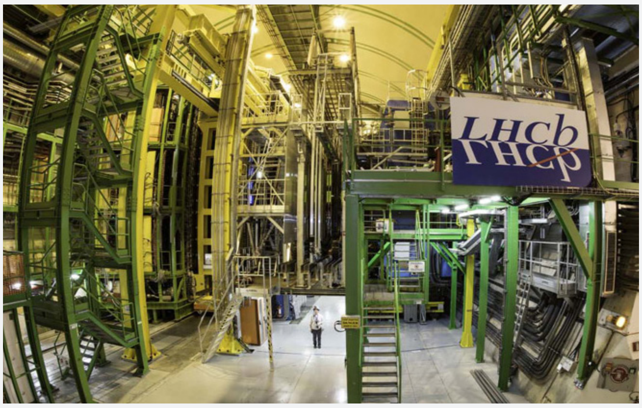

CP VIOLATION IN CHARM PARTICLES OBSERVED FOR THE FIRST TIME

An asymmetry of behaviour with respect to their antiparticles, called CP violation, has been observed for the first time in charm particle (containing a c quark, which has an electric charge of +2/3) decays. In particular, the CP violation was observed in D^0 mesons. The measurement was obtained by the LHCb detector at CERN's LHC accelerator and was coordinated by the INFN Bologna Divison, which is participating in the scientific collaboration of the LHCb experiment.
The result, which has a statistical significance of 5.3 standard deviations, was presented on March 21st at the Rencontres de Moriond EW conference and during a seminar at CERN.
Quarks can be divided into two categories: those of the "up type" with a +2/3 charge called up (u), charm (c) and top (t) quarks, and those of the "down type" with a -1/3 charge, i.e. the down (d), strange (s) and beauty (b) quarks. Property differences between matter and antimatter resulting from the so-called CP-symmetry violation phenomenon had been observed in the past only in the decays of strange and beauty particles, i.e. particles containing s quarks or b quarks. CP violation had never been measured before in the decays of particles containing quarks with a +2/3 charge.
The CP violation phenomenon was first observed in 1964 in the decay of neutral K mesons, and the two physicists who made the discovery, James Cronin and Val Fitch, were awarded the Nobel Prize for physics in 1980. At that time, the discovery was a great surprise to the particle physics community, then firmly convinced that CP symmetry could not be violated.
Thus the problem of how to include it in the mathematical description of the theory arose. A first theoretical contribution, subsequently fundamental for the development of a complete description of the phenomenon, had already been provided in 1963 in a famous article by Nicola Cabibbo, who had understood that the weak interaction 'interprets' particles composed of quarks as the result of mixing their various types. Starting

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from the foundations laid by Cabibbo, in the early 1970s, the Japanese Makoto Kobayashi and Toshihide Maskawa realised that CP violation could be included in the theoretical framework that we now know as the Standard Model of elementary particle physics provided that at least six different types of quarks existed in nature. The matrix that describes the mixing of the quarks was subsequently called the CKM matrix, from the initials of the surnames of the three theoretical physicists. The idea was definitively confirmed three decades later with the discovery of CP violation in the decay of beauty particles by the BaBar experiments in the United States and the Belle experiments in Japan, a result that led to the award of the Nobel prize for physics in 2008 to Kobayashi and Maskawa.

This measurement will stimulate renewed theoretical work to evaluate its impact on the description provided by the CKM matrix in the context of the Standard Model, and will open the way to the search for possible new CP violation processes in charm particles. ■

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The first “B - anti-B like” event in the Belle II Phase3 physics run